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# The Dynamic Behavior of Valve Reeds in Receiprocating Gas Compressors - Experimental Study

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THE DYNAMIC BEHAVIOUR OF VALVE REEDS IN RECIPROCATING GAS COMPRESSORS
EXPERIMENTAL STUDY

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ABSTRACT

An experimental investigation was made of the dynamic behaviour of a valve reed when subjected to a cyclically varying pressure difference across it. Displacement at points on the reed were obtained by a Wayne Kerr displacement transducer: a Kistler piezo-electric transducer was used to measure the pressure-time history across the valve.

There was good agreement between the experimental values of displacement and theoretical values. The theoretical values were predicted by a simulation model, based on the finite element method, discussed in a previous paper (1)

EXPERIMENTAL APPARATUS

Fig. 1 is a schematic diagram of the experimental circuit.

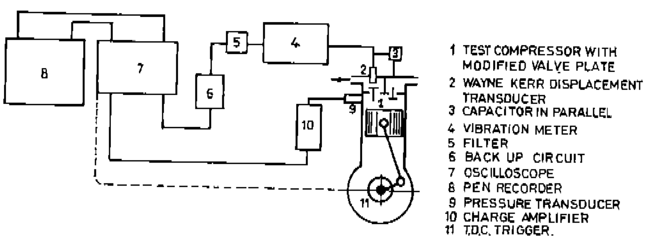


FIG. I. EXPERIMENTAL CIRCUIT

A single cylinder compressor pumping air was driven through vee-belts by a variable speed electric motor. The original discharge valve had a relatively complex geometry and a backing plate. To simplify this initial study and reduce the computer time and capacity required to obtain the corresponding analytical results, a cantilever reed clamped at the root replaced the original discharge valve (Fig. 2).

A small stud on the drive pulley of the compressor passed an electro-magnetic pick-up and generated a signal which indicated the TDC of the piston.

A Wayne Kerr capacitive transducer was used to record displacement at points along the centre line of the reed (Plate 1).

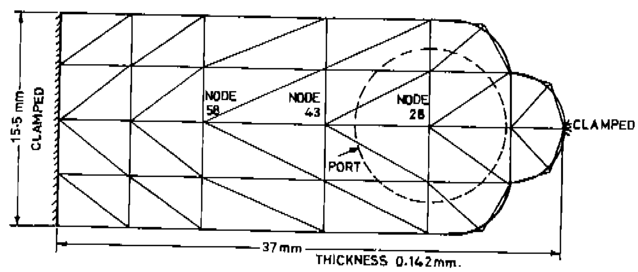


FIG. 2 FINITE ELEMENT MODEL OF CANTILEVER REED VALVE

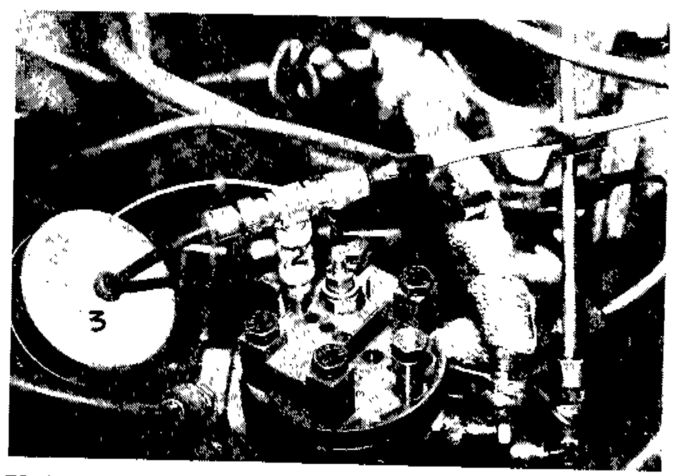


Plate 1 Cylinder head with pressure transducer (1) displacement transducer (2) and screened capacitor in parallel.

The circuit used to measure reed displacement included a high gain feedback amplifier, and could have provided linear relationship between displacement and voltage generated. However, the small size of the reed and the relatively large displacements involved prohibited the use of a standard displacement probe having sufficient range yet small enough to measure the displacement over an adequately small area on the reed. The probe used had a nominal range of displacement of 0.001 inches. With a screened concentric 30 pF capacitor in parallel the range of the transducer was extended but its linearity was lost and so (static) calibration was necessary.

The modified displacement transducer was then able to measure displacement and vibration amplitudes from 1.25 μm to 2.5 mm over a frequency range from DC to 10 kHz.

The system used to measure pressure, comprised three parts:

- Kistler quartz piezo-electric transducer, and associated charge amplifier,
- Gould-Advance digital storage oscilloscope with read-out facilities and a Watanabe multi-channel servo-operated pen recorder having a frequency response up to 80 Hz.

The transducer has excellent linearity and frequency response. The method of holding the transducer ensured precise location. The charge generated by the transducer was converted in the charge amplifier to a proportional electrical voltage which was recorded on the digital storage oscilloscope and then transferred to the pen recorder.

The output of the displacement meter was adjusted by waves of a DC voltage injected circuit so that the highest possible gain in the oscilloscope (consistent with noise level) could be adopted.

A high degree of consistency was obtained in the experimental results. However, the oil passing during compressor operation affected measurement of the reed displacement: the di-electric constant of the fluid between the probe and the reed changed with an increase in the signal up to 30%. Therefore the procedure included blowing off the oil just before measurements were taken.

There was pronounced flutter of the reed acting as a discharge valve at low compressor speeds. At higher speeds the valve remained open during the discharge phase without significant flutter.

## RESULTS

The experimental records were compared with results predicted by the finite element model discussed in a previous paper (1). The experimental and corresponding analytical records of reed displacement are shown in Fig. 3 and Fig. 3(a). The damping coefficient was assumed to be 1E-4 (Ref. 1). The agreement was considered to be good.

In the finite element model (i) used to predict the dynamic behaviour of a reed, all the elements are initially assumed to be coplanar. This was one reason why it was decided in this initial investigation to clamp the cantilever reed also at the tip so that the reed was essentially flat on the valve plate. Discrepancies between the measured displacements at points along the reed and those predicted were large when the reed did not sit completely flat on the valve plate and/or an oil film was present between the reed and the valve plate.

The finite element model had lower flexibility than the reed itself probably due to incompatibility properties of the elements used. The differences between experimental and predicted displacements tended to be more pronounced near the clamped root of the reed (Fig. 3). Ideal clamping cannot be achieved in practice. Therefore it was anticipated that the experimental records would show higher flexibility near the clamped root.

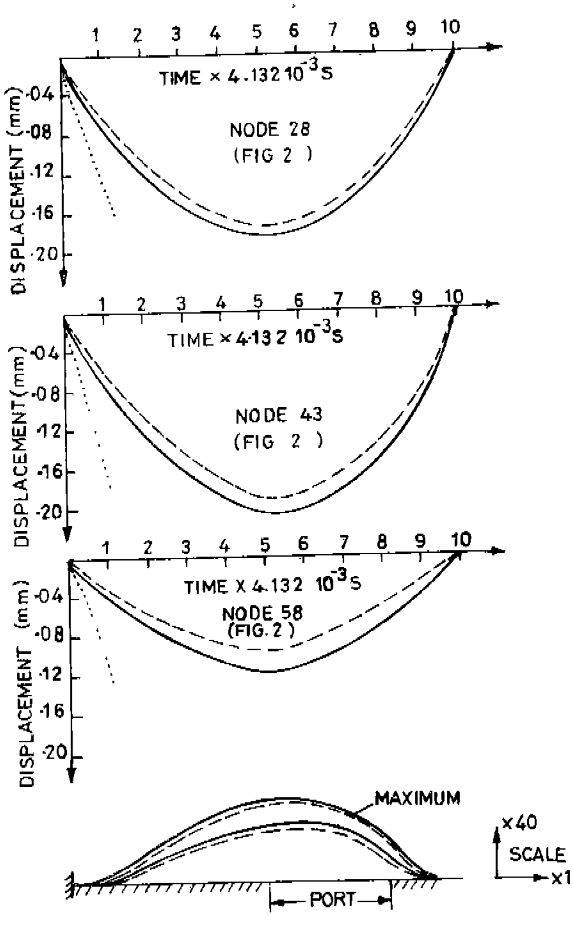


FIG. 3 VALVE REED DISPLACEMENT

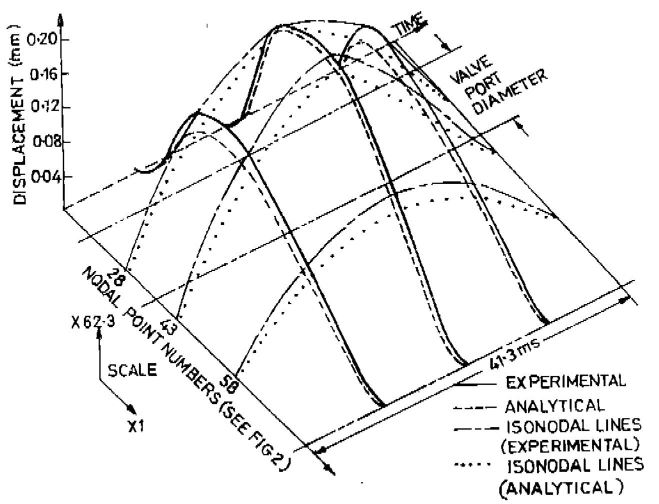


FIG.3 (a) REED DISPLACEMENT PATTERN UNDER DYNAMIC LOADING

The experimental results lie between two extremes of boundary conditions assumed in the analysis: at one extreme the clamping is assumed to be perfect, in the other the reed is free to rotate at the point of clamping. The experimental results in Fig. 3 lie closer to the first limit and suggest that good clamping had been obtained. To account for a restricted degree of rotation at the clamp, some extra elements with increased rigidity could be added at the root of the finite element model of the reed (1).

Small discrepancies between experimental and analytical results at node 28 (the port centre) may be a consequence of the applied force in the finite element being assumed concentrated at this point. In a compressor the gas force is distributed over the port area.

A further discrepancy may arise because the displacement probe, although the smallest available, has an averaging effect over the displacement of a finite area and cannot measure exactly the displacement at a point. Also it is not certain whether the finite element model (Fig. 2) was the best for this particular problem. Some of the elements have relatively high length/height ratio which might affect accuracy. Convergence studies and models with a greater number of degrees of freedom were not attempted at this stage due to the large requirement of computer time and capacity. Since the reed was clamped at root and tip without any free lift relatively large half-band width of the matrices had to be handled by the computer. The computer resources necessary are proportional to the size of the matrices (number of degrees of freedom of the finite element model), their half-band width and the time step used. An analysis of stability showed that time steps twice the critical time step (1) gave stable results. With larger time steps, instability occurred.

Damping of the valve movement is caused by external envelopment of the reed by gas and by internal dry friction. Damping was examined by exciting a similar reed (Ref. 1) in still air by an impact load and allowing it to vibrate freely. After the excitation the valve vibrated in its fundamental mode with higher modes superimposed. These higher modes died out quickly, however, and the decay of the fundamental mode was measured from a trace of the motion.

The logarithmic decrement $\delta$ is defined as:

$$\delta = \frac{1}{s} \ln \frac{X}{X_s}$$

where $X$ is the amplitude at any time and
$X_s$ is the amplitude s cycles later.

Fig. 4 shows the damping of the fundamental mode of vibration expressed in terms of an exponential decay for a typical suction valve reed.

Neglect of damping resulted in an error in the estimation of the fundamental natural frequency of only $2.47 \times 10^{-4}\%$. Damping of the valve reed is therefore almost negligible.

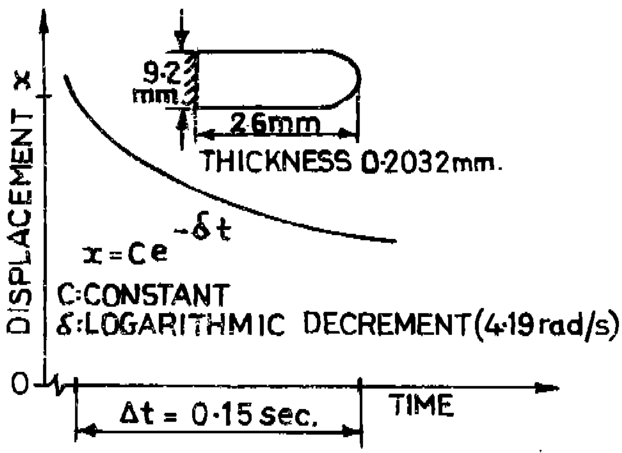


FIG.4. DAMPING OF THE FUNDAMENTAL MODE OF VIBRATION OF A TYPICAL SUCTION VALVE REED WHEN AN IMPACT LOAD IS APPLIED AT TIP

It had been assumed in the analysis that the damping coefficient was 1.0 E-4 (Fig. 3). A value of 1.0 E-5 or even less would be more appropriate (see Fig. 8, Ref. 1), and would have improved the correlation between analytical and experimental results in Fig. 3.

A damping coefficient of 1.0 E-4 results in a ratio of damping to its critical for the first mode shape of 0.015 while a damping coefficient of 1.0 E-5 would result in a value of 0.0015 (1).

The degree of damping imposed upon the reed in operation might be significantly greater than that obtained in the experiment due to a combination of the degree of clamping and the effect of aerodynamic gas loading. An increase of 4 - 5 times in the logarithmic decrement and about 18 times in the per cent error was experienced when the experiment took place in an air stream of about 50 lit/min.

## CONCLUSIONS

The displacement of points along a valve reed was measured under dynamic conditions. Good agreement was achieved between the experimental records and analytical results obtained from a simulation model employing the finite element method (1), particularly if damping effects have been over-estimated in the analysis.

Small discrepancies between experimental records and predictions by the model were considered to be due to imperfect clamping at the root of the reed in practice. The analytical model was able to account for this imperfection by including at the clamped root a degree of rotation restricted by an appropriate amount by adding extra finite elements with increased rigidity at the root.

## ANTICIPATED EXTENSION

A more realistic situation is being studied where the cantilever reed is clamped only at the root and has a free lift at tip as far as a point stop. Following a study of this geometry, typical of a suction valve, the discharge valve with backing plate as stop will be examined.

The theoretical model used predicts the stress patterns on the reed under dynamic conditions (1).

Comparison between measured stresses and those predicted by the model under dynamic conditions is being made.


## ACKNOWLEDGEMENTS

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## REFERENCE


1. S. Papastergiou, J. Brown & J. MacLaren. "The Dynamic Behaviour of Valve Reeds in Reciprocating Gas Compressors - Analytical Study".

   1980 Purdue Compressor Technology Conference.